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PENSOFT

The southernmost distribution range of *Isoetes panamensis* Maxon & C.V. Morton (Lycopodiopsida, Isoetaceae) in the relicts of the Cerrado in southern Brazil

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Abstract

Establishing the geographical distribution limits of species may provide not only data to understand their range of adaptation to conservation proposals but also records of the dynamics in the vegetation across the time. Here we report the southernmost limit of the occurrence of *Isoetes panamensis* Maxon & C.V. Morton within a relict of the Cerrado in Paraná, Brazil. This find highlights the importance of fieldwork in relicts of the Cerrado to enhance the knowledge about the flora of Paraná and the vegetational dynamic of the Cerrado in the past.

Keywords

Aquatic plants, dry diagonal, lycophytes, new record, niche conservation, savannah

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Introduction

The Cerrado, the Brazilian savannah, is the second largest biome in the Neotropics and a key region to understand the evolution and distribution of Neotropical biodiversity (Oliveira and Marquis 2002). Its core area is in the center of South America. Along with the Chaco and Caatinga, the Cerrado forms a diagonal of dry vegetation that separates two primary humid forests in the continent, the Amazonia and the Atlantic Rain Forest (Ab'Sáber 1977; Werneck 2011).

Historical changes in the climate have shaped the distribution of the Cerrado in Brazil (Behling 1995, 2003), with expansions and retractions of its limits during glacial and interglacial periods. These changes have promoted the occurrence of relicts of Cerrado in areas nowadays dominated by humid tropical Amazonia and the Atlantic Rain Forest. This is the case in Paraná, where the Cerrado has its southernmost limits (Maack 1981; Ratter et al. 2003) and where it is possible to find several plant species with a disjunct distribution with their core populations.

These marginal, disjunct populations are not only an essential record of the dynamics in the vegetation in the past climate oscillations but also represent genetic diversity, which is important in understanding the evolution of species and indispensable information for conservation (e.g., Yang et al. 2016; Abeli et al. 2018). Cerrado relicts,

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however, appear to be at risk in the state of Paraná due to their conversion to agriculture (Soterroni et al. 2019), and only a few remnants of Cerrado are still preserved.

The species of the lycophyte genus *Isoetes* L. are usually terrestrial and occur in seasonally inundated areas, or are fully aquatic and live submerged in ponds, lakes, and rivers (Taylor et al. 1994). The genus comprises approximately 250 species (PPG 1 2016), 78 of them occur in the Neotropics (Troia et al. 2016). Although having a worldwide distribution, the genus is usually rare, and most of its species occur in oligotrophic environments.

Phylogenetic studies of the Neotropical *Isoetes* species recovered two clades which are distinct not only by belonging to distant lineages but also by occupying different regions of South American (Pereira et al. 2017). One clade occurs mainly in temperate habitats such as at high altitudes in the Andes and in the coastal mountains of southeastern Brazil (Pereira et al. 2019), whereas the other clade occurs throughout tropical and warmer regions in the Neotropics (Pereira et al. 2017). Among the species of *Isoetes*, *I. panamensis* Maxon & C.V. Morton represents a species complex occurring mainly in areas with dry open vegetation in Central and South America. Thus far, its southernmost limits were known from core Cerrado areas in the state of Mato Grosso do Sul, central Brazil.

This apparent association of *I. panamensis* with tropical, dry, open environments led us to wonder whether this species would also occur in isolated Cerrado patches in Paraná, which is characterized by its transitional tropical and subtropical climate. Motivated by hypothesis, we endeavored to find *I. panamensis* as a contribution to understanding not only the floristic makeup of these relicts but also the biogeography of the genus.

Methods

Fieldwork was carried out from 2010 through 2018 in Cerrado areas in the municipalities of Campo Mourão, Guartelá, Jaguariaíva, and Tuneiras do Oeste (Paraná, Brazil) (Fig. 1). These areas represent the prominent remnants of Cerrado in Paraná. We also studied the collections of the CGMS, HCF, MBM, RB, and UPCB Herbaria, and virtual collections on the SpeciesLink (2020) and Reflora Herbário Virtual (2020) databases.

Habitat, life form, color, size, and ornamentation of the mega- and microspores, the proportion of the sporangium wall covered by the velum, and number and size of leaves were used to identify the species. The megaspores and microspores were analyzed using scanning electron microscopy. Images of the spores were made by transferring the spores to aluminum stubs coated with a carbon adhesive. The stubs were then coated with gold-palladium alloy in a sputter-coater for 180 s, and then digitally imaged using a Zeiss SIGMA VP. Spores of collected specimens were compared with the type to ensure the correct morphological identification of the samples.

We used QGIS v. 2.18.11 (QGIS.org 2016) to draw the geographic distribution map and compare the previously known occurrences of the species with the newly recorded population. In Brazil, the Cerrado was defined as by IBGE (2019). As for other tropical areas in the Neotropics, we followed the ecoregions of Olson et al. (2001).

Results

***Isoetes panamensis* Maxon & C.V. Morton**, Annals of the Missouri Botanical Garden 26: 272. 1939. (Maxon and Morton 1939)

Type: Panamá • Pond, vicinity of Bejuco, 7 August 1938, Woodson, Allen & Seibert 1685 (US!)

New records. BRAZIL • Paraná, Tuneiras do Oeste, near to Reserva Biológica das Perobas; 23°54′50″S, 052° 45′03″W; 510 m alt.; 4 June 2018; M.L. Brotto et al. 2671; HCF000027726, MBM413838, RB01412422 (Fig. 1).

This population was found as terrestrial in the hydromorphic soil near a stream crossing a savannah fragment (Fig. 2A, B). The area presented a combination of herbaceous and shrub vegetation elements (Fig. 2A).

Identification. The newly recorded population showed the diagnostic characters found in the type of *I. panamensis* such as the presence of megaspore baculates, microspore echinates (Fig. 2C), velum significantly reduced to absent, and leaves 20–40 cm long, 25–50 per individual.

Description. Plant aquatic or terrestrial in hydromorphic soils. Corm globose, 3-lobate, ca. 3 cm wide. Leaves 1.8–2.0 mm wide at the middle length, 30–35 cm long, ca. 50 per individual, linear, lax, erect, apices acute. Labium present, persistent, 4.0–4.5 mm wide, 1.5–1.9 mm long, deltate. Sporangium rudimentarily covered by a velum, 6.5–7.0 mm wide, 13–15 mm long, obovate. Megaspores trilete, white, 500–600 µm in diameter, proximal and distal surfaces baculate. Microspores monolete, 29–34 µm long, proximal and distal surfaces echinate.

Discussion

Isoetes panamensis is a species complex closely associated with open, warm, dry habitats occurring in tropical dry forest and savannah (Fig. 1). Although many of the specimens currently identified as *I. panamensis* may represent distinct species, the group's taxonomy is complicated due to its morphological simplicity and convergence. Phylogenetic studies have recovered the *I. panamensis* complex in a clade along with other species from tropical Central and South America (Pereira et al. 2017). However, relationships in this clade are highly unresolved, making unclear the delimitation of potential, undescribed new species within this complex. Furthermore, polyploidization is important in the speciation in *Isoetes* (e.g., Hoot et al. 2004; Kim et al. 2010; Pereira et al. 2019) and is a confounding factor to resolve the taxonomy and phylogeny of *I. panamensis* complex.

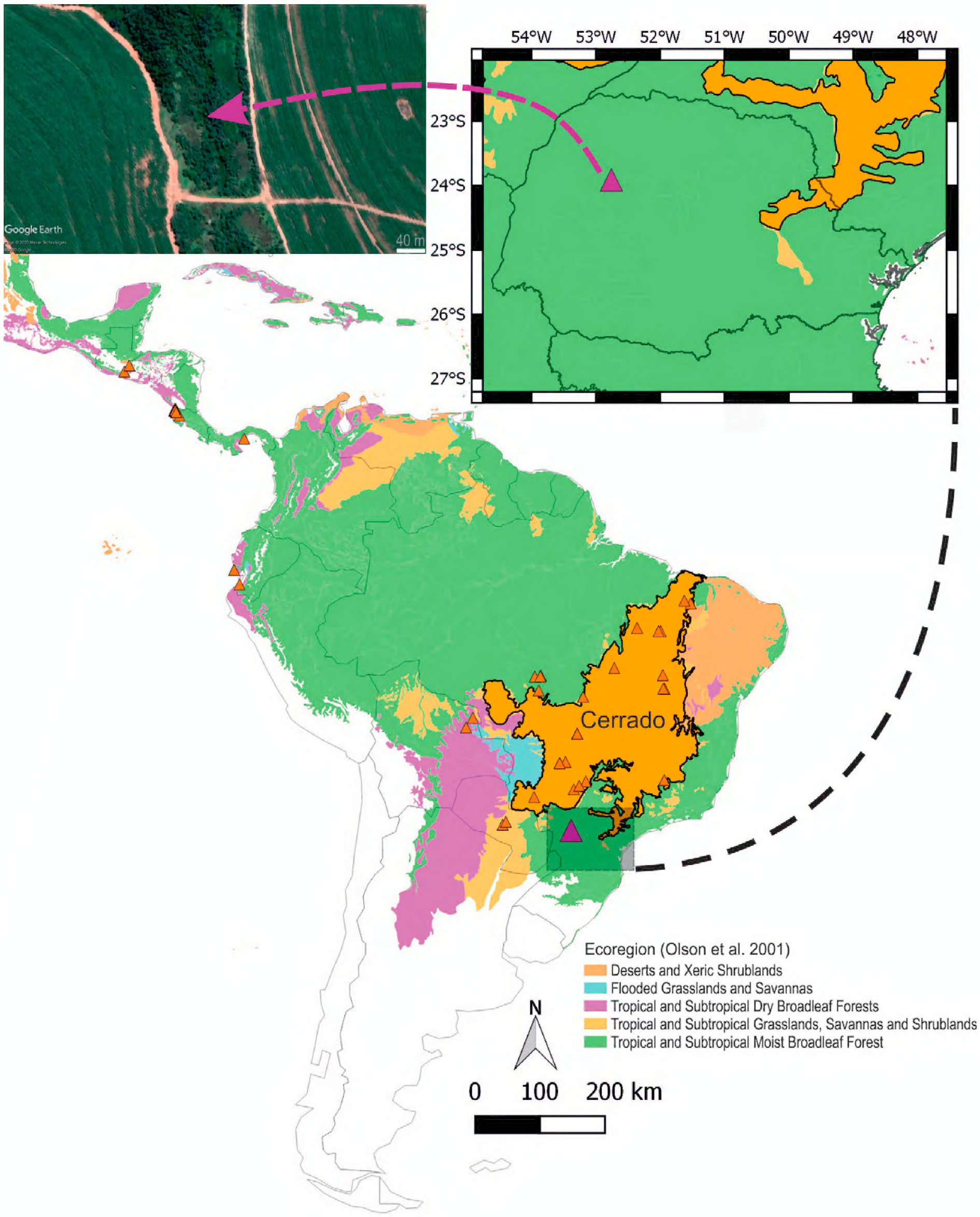

Figure 1. Distribution range of *I. panamensis* (orange and purple triangle). The newly recorded population in Paraná is pointed by the purple triangle (Google Earth image is attributed to Image ©2020 Google, Maxar Technologies).

The marginal populations can reveal the limit of adaptation and morphological and genetic variation of a species (Yang et al. 2016; Abeli et al. 2018). The new Cerrado relict locality of *I. panamensis* represents the southernmost occurrence of this species complex (Fig. 1) and this population might provide key information to untangle the evolution in this group. Moreover, the collection of this species in an isolated fragment of the Cerrado corroborates a close relationship of this species with a warm, tropical environment, which appears to reflect the niche conservation in its clade.

Interestingly, *I. panamensis* is currently only known in Paraná in an isolated fragment of Cerrado. This occurrence may be related to the rarity of this species and its

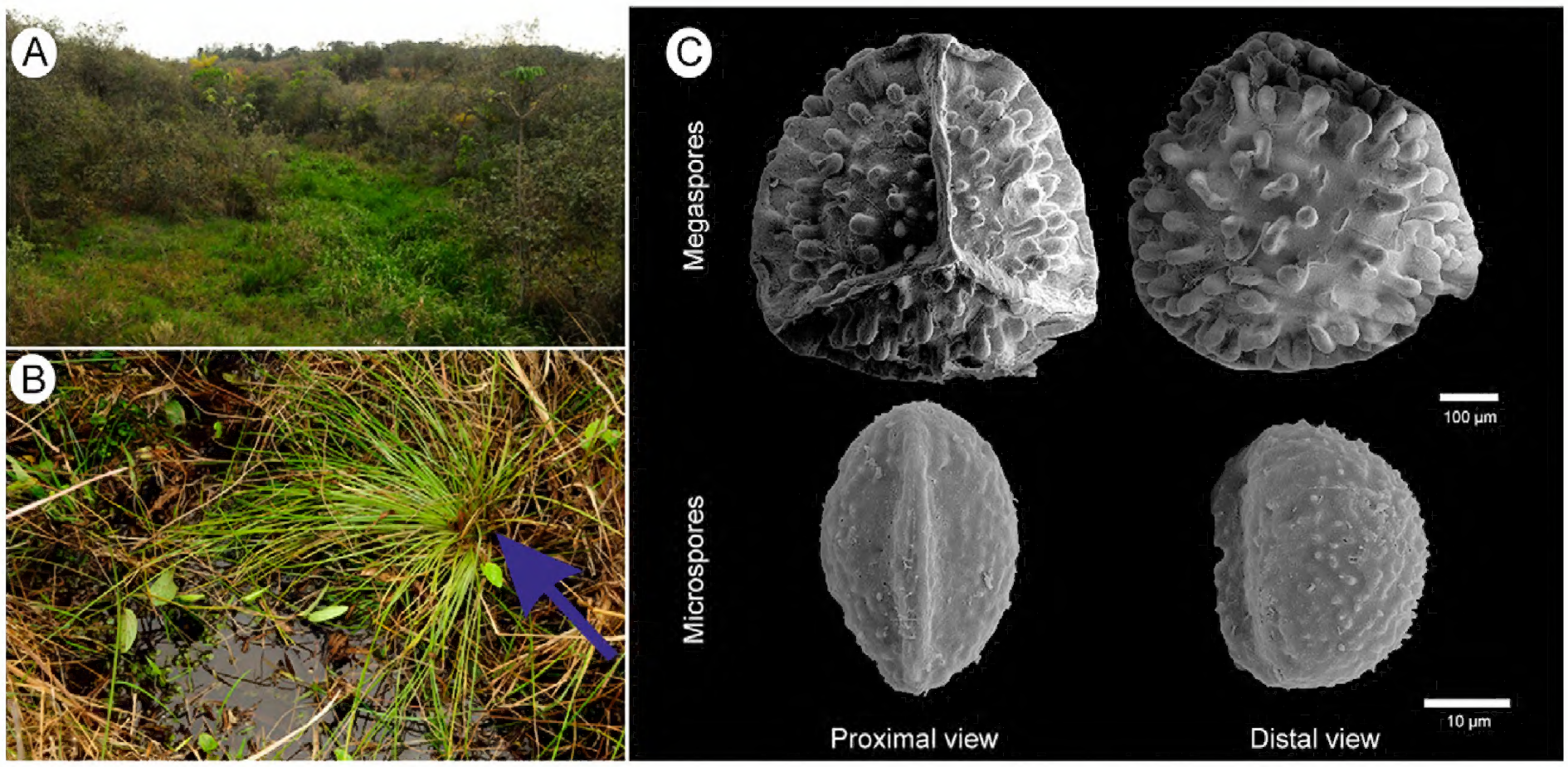

Figure 2. Habitat and morphological characteristics of *I. panamensis*. **A.** Habitat with herbaceous and shrub vegetation elements. **B.** *Isoetes panamensis* in hydromorphicsoil. **C.** Megaspores and microspores.

resemblance to tufts of grass, leading this plant to pass easily unnoticed (Fig. 2B). Several floristic surveys have provided accurate information about the diversity of ferns and lycophytes in remnants of the Cerrado in Paraná (Schwartsburd and Labiak 2007; Michelon and Labiak 2013; Michelon et al. 2018), but none of them recorded *I. panamensis* in those areas. We hypothesize that the difficulty of finding this species in the field and its ecological specificity (i.e., open vegetation and edaphic and climatic conditions such as those found in the Cerrado) may influenced the paucity of *Isoetes panamensis* records in the state.

It is noteworthy that Paraná is also the southern limit of several species of predominantly tropical grasses, showing the importance of the tropical floristic contingent in the composition of grasslands in the state (Ritter et al. 2010). However, *I. panamensis* appear to differ from these grasses in occurring exclusively in Cerrado areas, which is congruent with the tropical distribution range of its clade.

In Paraná, the Cerrado presents most of its remnants in the Campos Gerais region (Maack 1981). Although these fragments are located in a transitional zone between subtropical and tropical floristic elements, they have a great affinity with the savannah formations of São Paulo and the Central Plateau of Brazil (Ratter et al. 2003; Ritter et al. 2010). On the other hand, where *I. panamensis* was found in northwestern Paraná was almost entirely covered by the Semideciduous Seasonal Forest, which is one of the vegetation types of the Atlantic Forest biome, and by small savannah patches (Maack 1981; Roderjan et al. 2002). The northwestern part of Paraná currently contains only 8–20% of its original vegetation, depending on the micro-region analyzed (SFB 2018). In this region, the largest fully protected area is the Perobas Biological Reserve (23°47′S, 023°55′W) in the municipalities of Tuneiras do Oeste and Cianorte. This area comprises ca. 8,716 ha with Semideciduous Seasonal Forest as its predominate vegetation element (ICMBio 2013). Although this reserve has been intensely botanically explored by the Campo Mourão Herbarium (HCF) and the Municipal Botanical Museum of Curitiba (MBM), *I. panamensis* was only found in a private property at about 5 km south of this protected area. The occurrence of this population only on private land and the increased expansion of soybean plantations in this portion of the state implies that this species is at risk in Paraná.

In conclusion, Paraná is one of the few Brazilian states that present a published list of its flora (Kaehler et al. 2014). Although this provisional checklist enhanced our knowledge of the flora of Paraná, it is far from complete, as fieldwork in relict Cerrado area is still finding species previously unknown from the state. We hope that our new record prompts more intensive fieldwork efforts in few remaining Cerrado patches, which is highly endangered habitat that is demonstrably refuges for rare species from the savanna.

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Authors' Contributions

JBSP identified the specimens, wrote and designed the

article. MB collected the specimens and wrote the article. PHL wrote and designed the article.

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